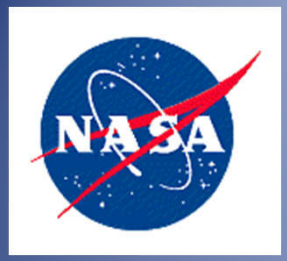

FINDER

FINDING INDIVIDUALS FOR DISASTER AND EMERGENCY RESPONSE

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Homeland Security
Science and Technology

DHS S&T Mission

Strengthen America's security and resiliency by providing knowledge products and innovative technology solutions for the Homeland Security Enterprise

The Challenge

FINDER

Photo Credits: Cypress Frwy, USGS H Wilshire; Marina District, USGS J Nakata; CSUN, Ken Fowler; Northridge Apt, Gregory Davis; ground zero 911, US Navy J Watson; Tornado & rest, FEMA;

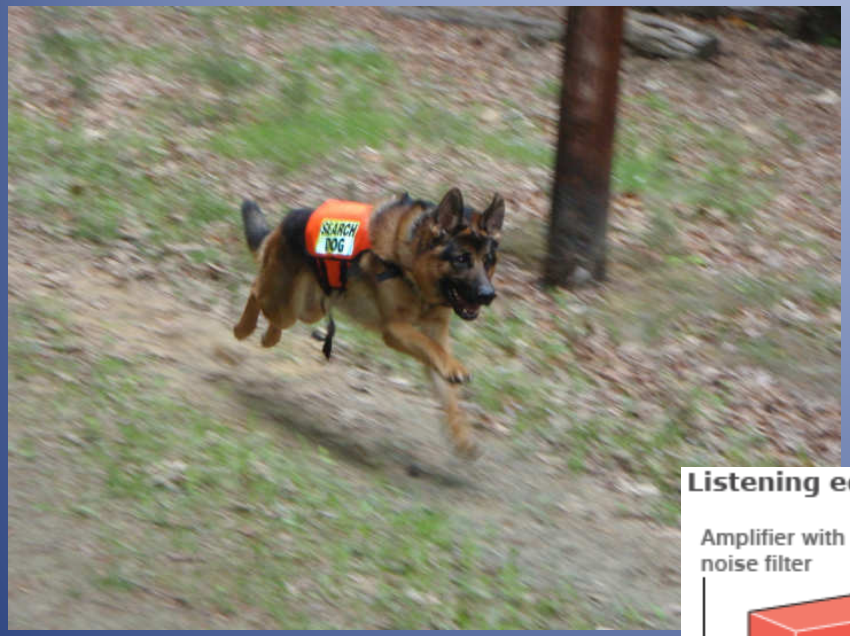
Looking for the Holy Grail of SAR

"Walk down a street with collapsed buildings and readily determine which have live humans in them!"

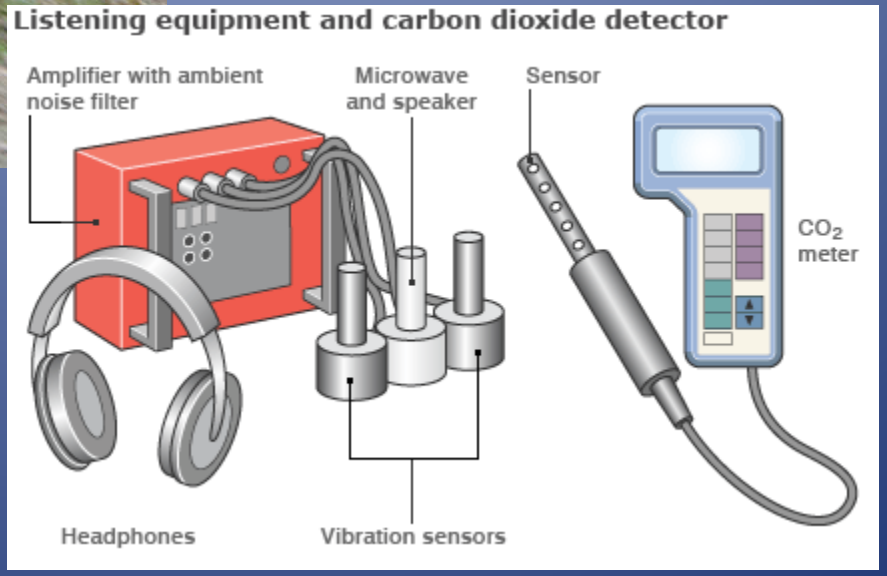
Time spent searching is lives saved or lost!

FINDER

How SAR teams do it now



Topas – Photo courtesy John Price



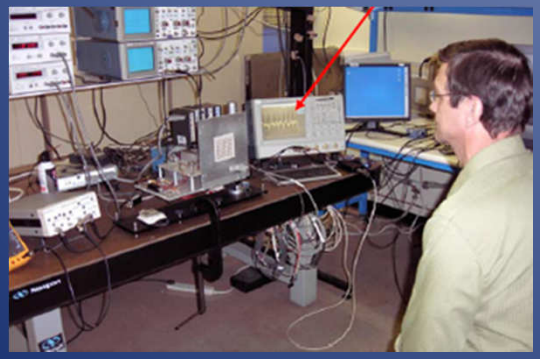
Courtesy BBC

FINDER

FINDER

Finding Individuals for Disaster and Emergency Response

- DHS wanted 80% solution today, not a 100% solution in 5 years
  - Existing search techniques aren't 100%
  - New approaches that are complementary to existing approaches, not replacements
- JPL has technology that can get us there
  - Microwave Sensing of Human Vital Signs
  - Just another remote sensing problem, isn't it?
- Project started in April 2012, first prototype tests in Apr 2013



FINDER

FINDER

- Portable multi-channel radar
  - Airline carry-on
  - Handheld waterproof tablet for control
- Easy to operate
  - Sets up in a minute or two
  - 30-60 seconds to collect data and do signal processing to display heart and respiration rates with confidence levels (related to SNR)
  - Records a photograph of search location and GPS data along with raw and analyzed data
  - 12 hour rechargeable battery life. Swapping freshly charged batteries takes seconds.

Salman Haque testing FINDER prototype at rubble test site on JPL Mesa

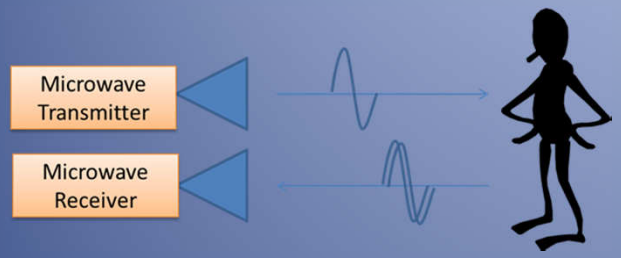
FINDER

Original User Scenario Requirements

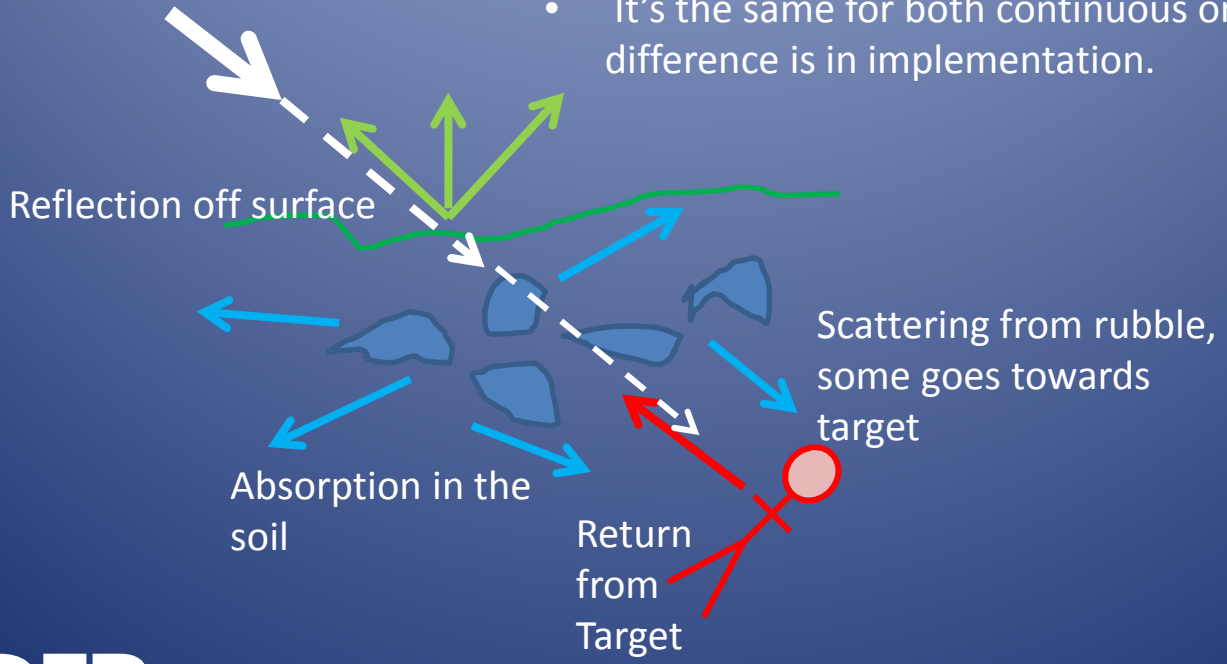
Goal Parameter	Original and revised values	Demonstrated Performance
Site size & materials	10x10 meters, 3 meters thick, mixed concrete, brick, household effects or office furniture + rain & mud	30x50 meters or more Detection through 10 meters (35 ft) of mixed concrete & reinforcing steel Detection through 15 m (50 ft) of simulated residential collapse (appliances, furniture) Detection at 30 meters (100 ft) through forest
Scanning	10 minutes to scan a site from up to 20 meters away Be able to scan 30 sites in 8 hrs	90 seconds per scan. 40 minutes to walk around a 30x50 meter rubble pile and perform 20 scans
Location precision	Rough Indication (FINDER is a "detector" not a "locator")	Separates targets in front from bystanders and behind
Operators	One person operable	
Portability and setup	Equipment carried by One person Battery powered Setup in <10 minutes, Teardown in <10 minutes	Fits in overhead compartment, 20 lb Battery life is 14 hours Setup and stow in 2 minutes each.
# of simultaneous victims	5 per site individually distinguishable. Detect more if possible. Distinguish between humans and animals or machinery	Demonstrated with 3 victims in same physical spot and 3 others in rubble. Rejects mechanical devices and non-human heart rates
Environment	"outdoors", neither rain, nor snow, nor dark of night, etc…	Waterproof, usable day or night

FINDER

How the Radar Works



- The radar illuminates the rubble pile (like a bright searchlight), and we get reflections back from everything, including the victim.
- But, only the victim is moving (breathing and heartbeat), so we look for tiny changes in the reflection.
- Phase change is about 6º-7º due to small (1mm) motions of victim's body due to heartbeat
- It's the same for both continuous or pulsed radars. The difference is in implementation.



FINDER

The Limits of Performance

- The simple fixed clutter model (as well as 30 years of researchers) shows that you can detect heartbeats through quite a distance:
  - It's all about having a enough radar power and cancelling the clutter signal. We're using thousandths of a watt.
- To the radar signal, the rubble looks a lot like fog, or pebbled glass: you can shine a flashlight through, but even so, the images are hazy and distorted.
  - We know someone is there, but, "where are they?"
  - Computer models show best possible distance accuracy of 20% of the range, angles accuracy of 20-30 degrees.
- Meets Urban Search and Rescue need for the "detect" phase of the search

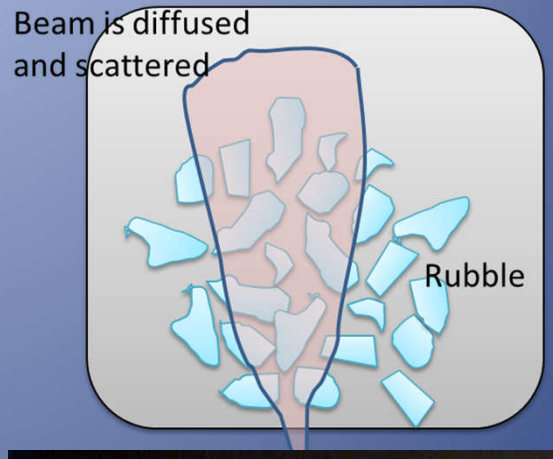


Photo © Lloyd Kahn/www.lloydkhan.com
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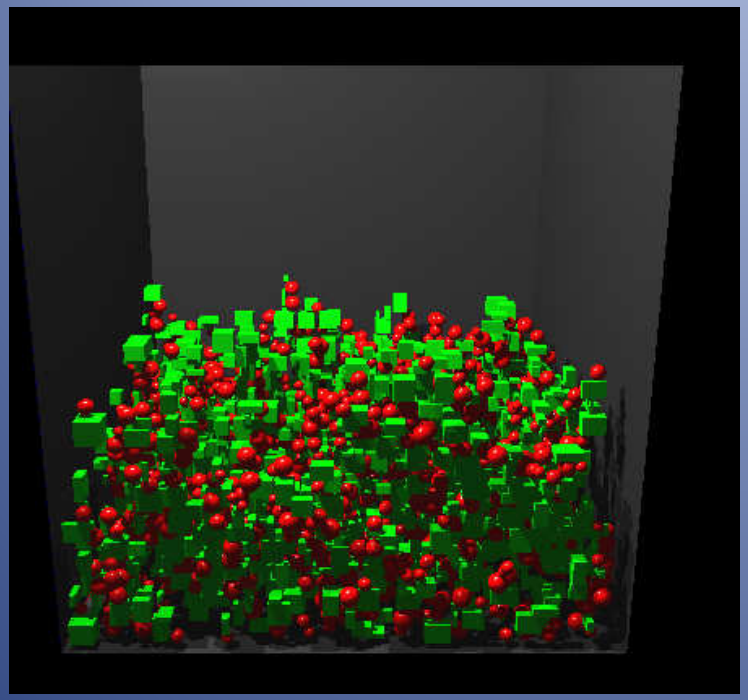
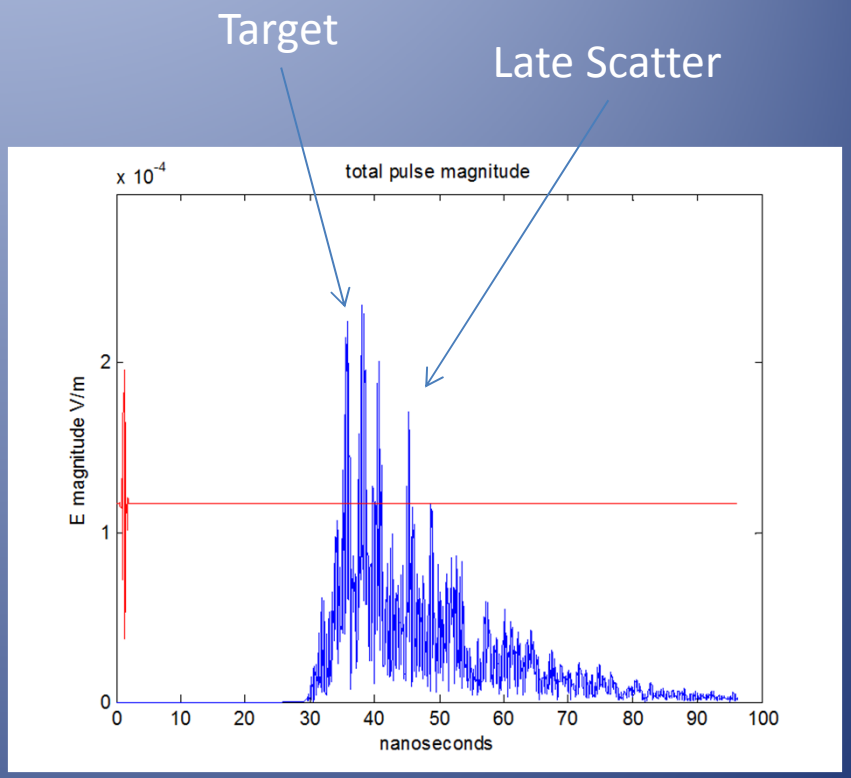
FINDER

Computer simulation
Radar signals in rubble



5m, 16 ft

Mud not shown



1 foot is about 2 nanoseconds in rubble

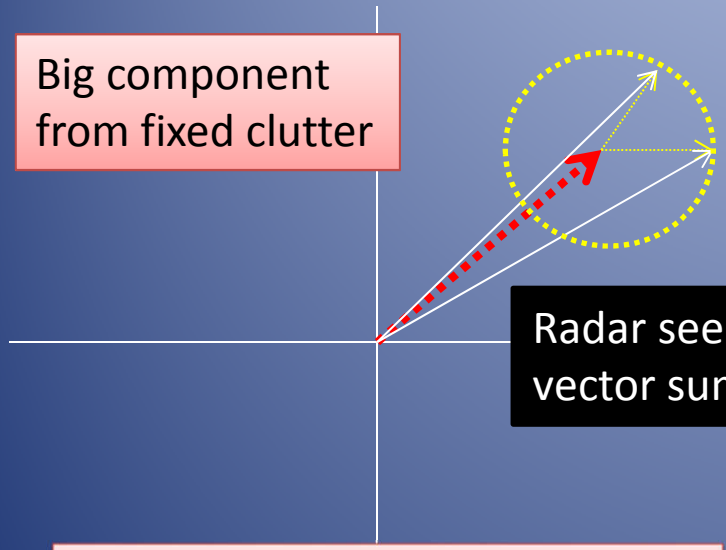
- Scattering limits the accuracy of range measurement to about 20% of range.

FINDER

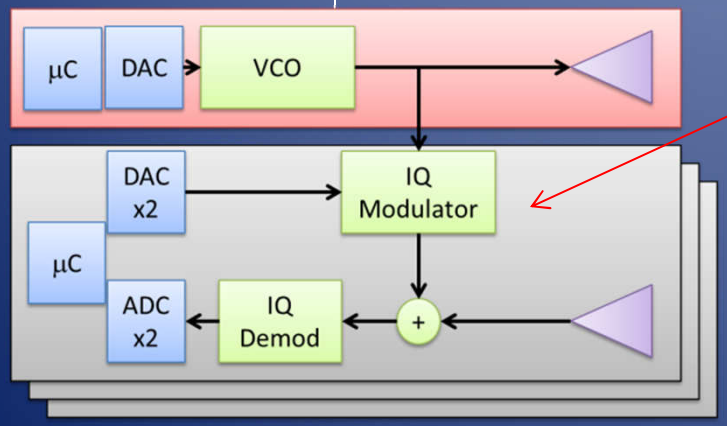
Fixed clutter canceller improves dynamic range

Big component from fixed clutter

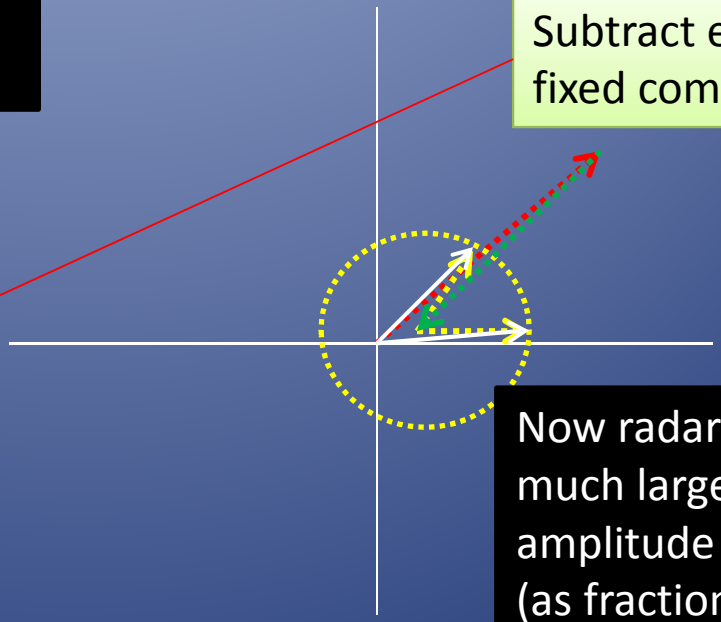
Small changing component from heartbeat & breathing. Constant amplitude, variable phase



Radar sees the vector sum



Subtract estimate of fixed component



Now radar sees much larger phase & amplitude variation (as fraction of total signal)

FINDER

FINDER Architecture

WiFi

PC for target detection

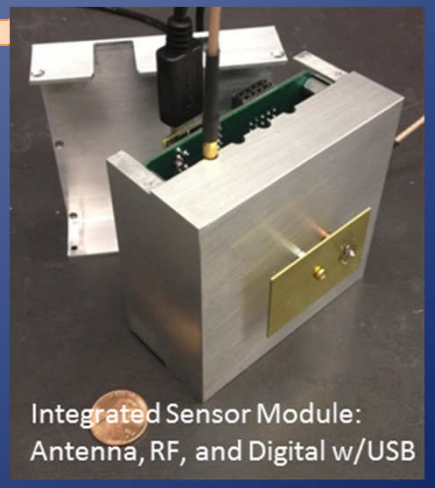
USB

Batteries

Camera

GPS

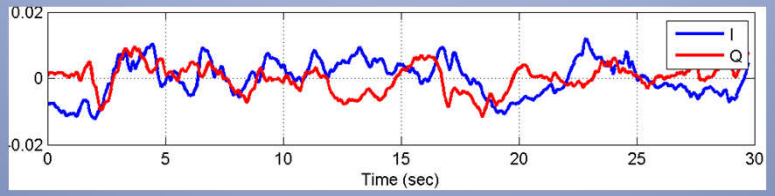
µC	Tx RF module	Antenna
µC	Rx RF module	Antenna
µC	Rx RF module	Antenna
µC	Rx RF module	Antenna
µC	Rx RF module	Antenna



FINDER

Data Processing Flow

FINDER Sensors



Feature Extraction

	freq	SNR	BW	FM F
breathing	0.174	29.2		
	0.246	22.8		
	0.607	16.6		
heart	1.03	15.3	0.024	0.16
	1.27	16.0	0.025	0.29
	1.57	9.8	0.023	0.34

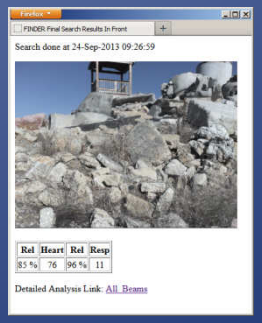
Victim Detection

Rel	Heart	Resp
84 %	74	15

Camera Image

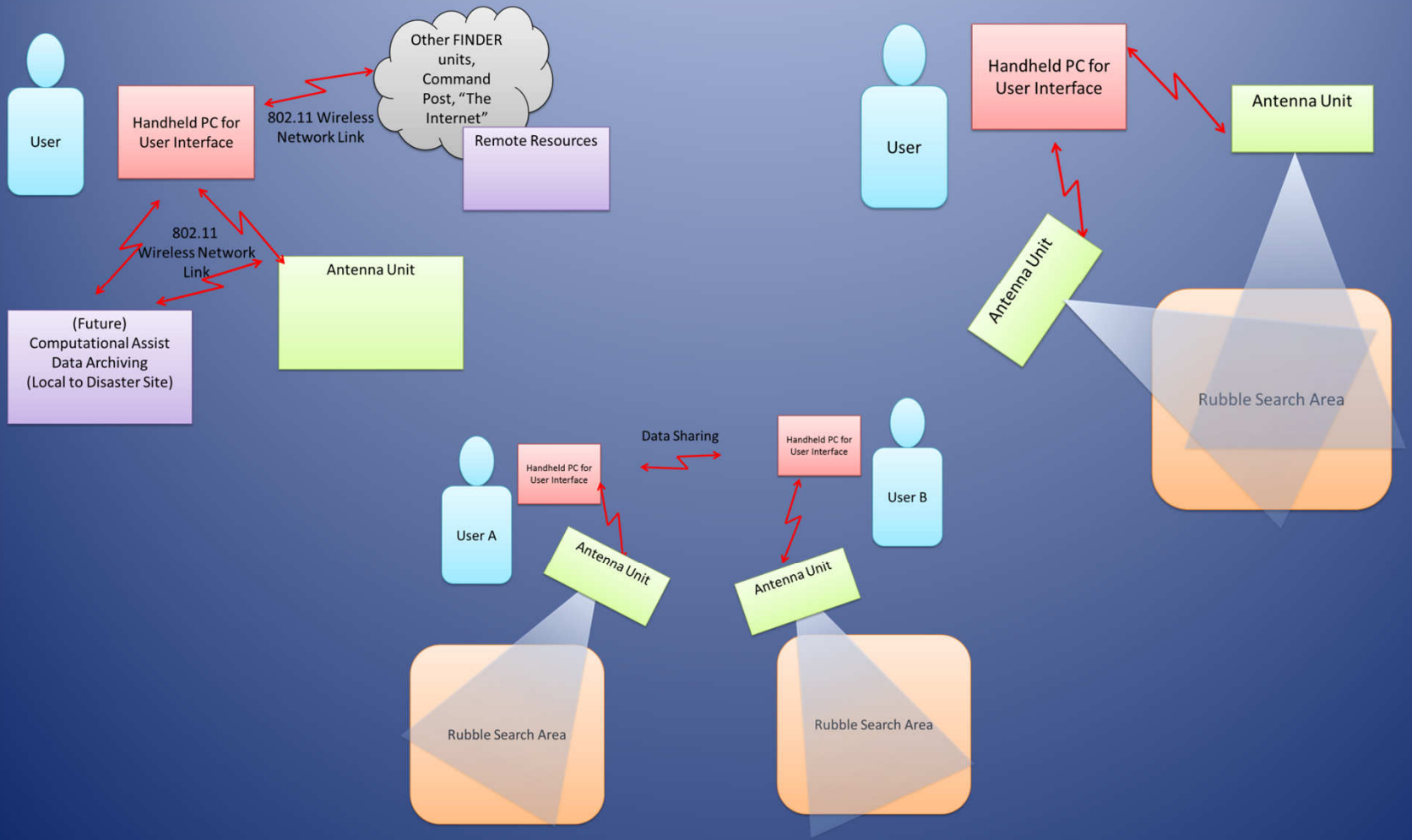
GPS data

User Display



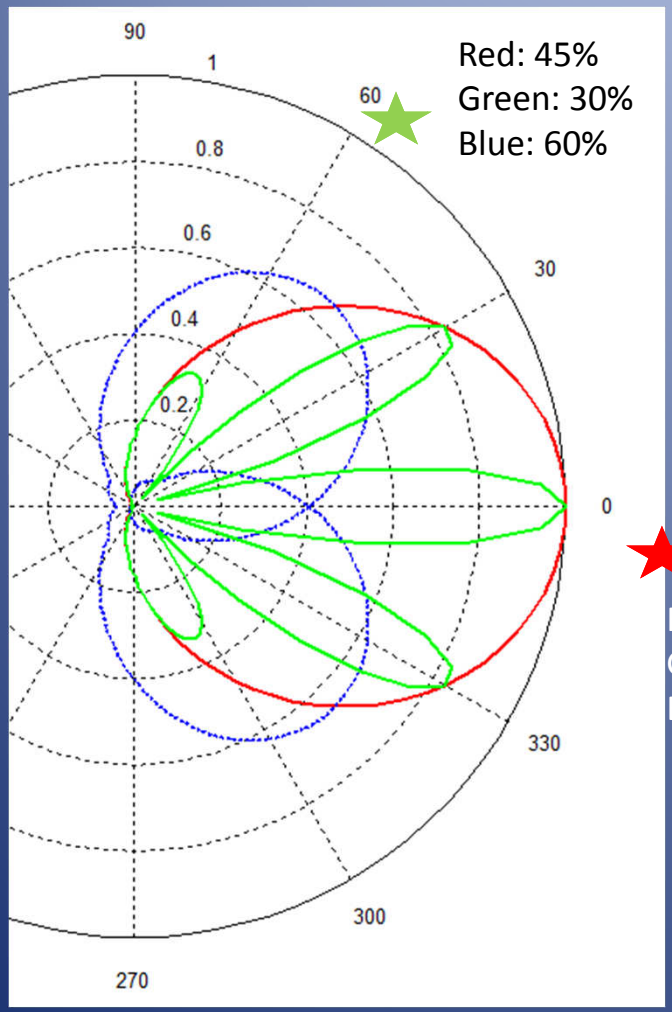
FINDER

Wireless Network Enables Many Configurations



FINDER

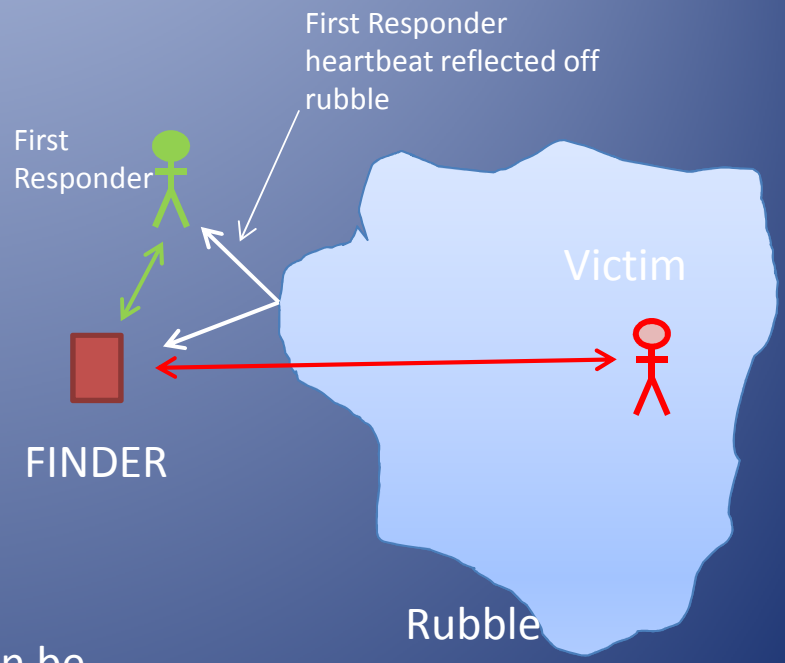
Multiple Antennas & Beams allow distinguishing desired targets from others (reflected off rubble).



Red: 45%
Green: 30%
Blue: 60%

Red: 100%
Green: 100%
Blue: 40%

Targets can be distinguished by relative strength and direction



FINDER

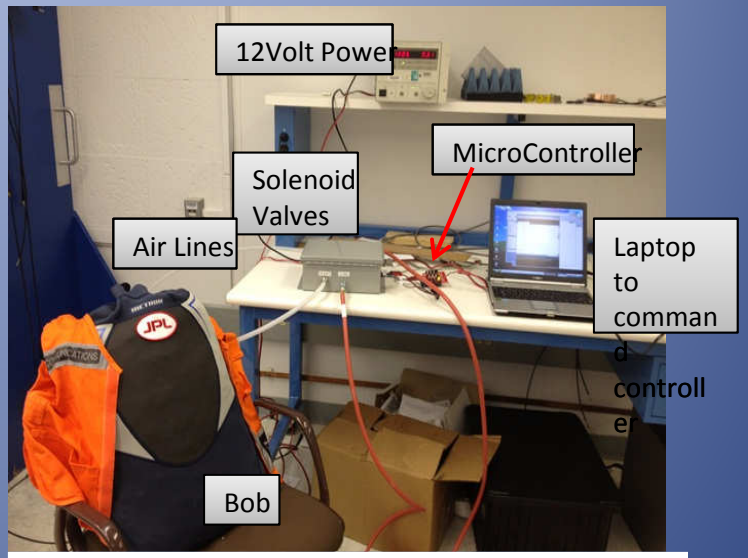
Objective Testing & Calibrated Targets

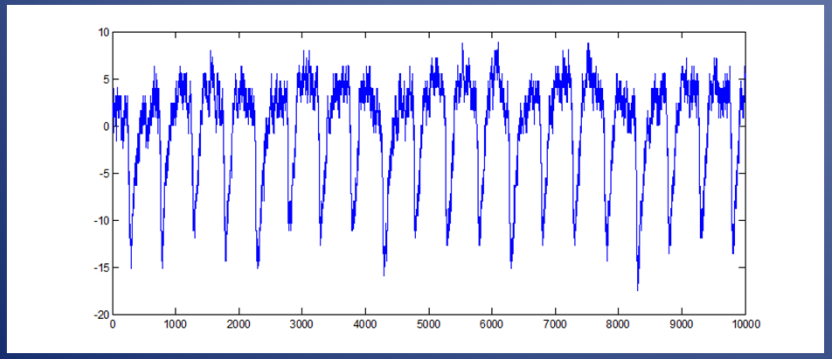
- Journal literature and previous research has used human subjects, but..
  - Humans aren't consistent from one day to the next
  - Humans can't change breathing and heart rate on command for testing
  - Humans don't like being buried in rubble for days on end
  - Human testing requires "Institutional Review Board" approval (which we have).
- So we have built and tested several artificial targets
  - Voice coil positioner with reflector
  - Anthropomorphic dummy
- Field testing at JPL Rubble site with humans and artificial targets

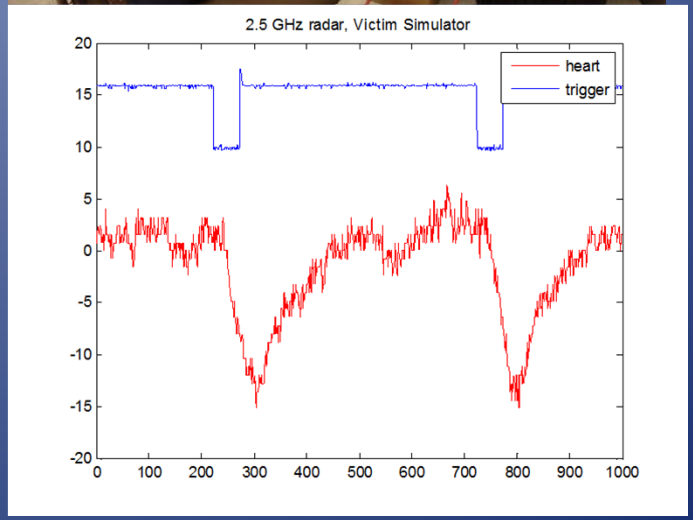
FINDER

Anthropomorphic dummy

- Realistic RF properties: absorption and reflection matches humans due to gel-like filler
- Realistic motion: lungs and heart that inflate/deflate with air, controlled by a microprocessor
- Can't do "fine motion details" but we can change breathing patterns and heart beats
- Buryable in rubble for testing







FINDER

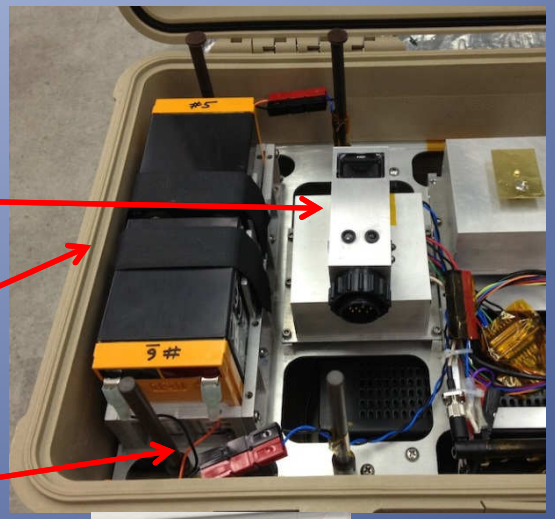
Using FINDER

- Preparing for searches
- Search Strategies

FINDER

Getting FINDER Ready

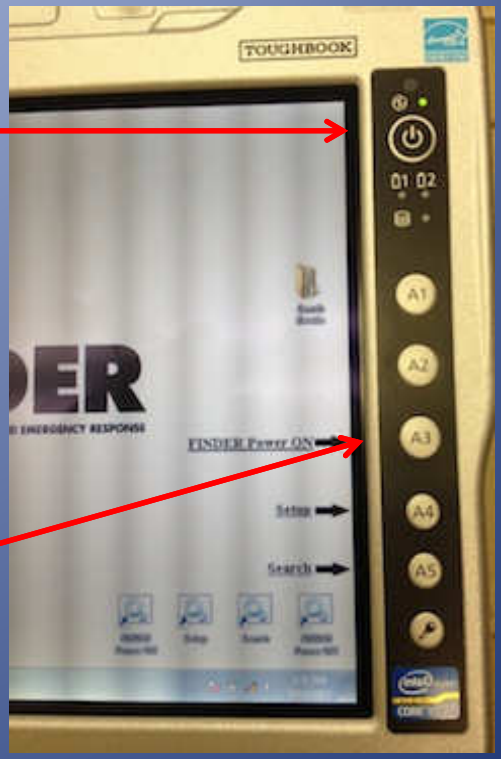
- Open the case
- Remove the camera/beacon
- Check the batteries and connectors
- Install the beacon on top



FINDER

Using FINDER

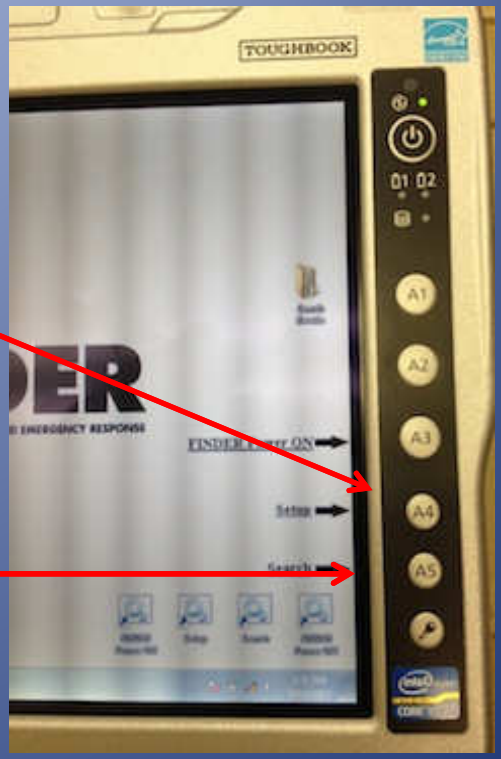
- Turn on the Toughbook first
  - The button in the upper left corner
- Camera/Beacon is stored inside FINDER.
  - Putting it on is “turning on the master switch” so that the Toughbook can control FINDER
  - Press the A3 button to turn power on (or click on the icon)
  - It takes about a minute for FINDER to start up and communicate with the Toughbook



FINDER

Setup and Search

- Put FINDER in the search area
- Click the “setup” button
  - FINDER takes about 30 seconds to measure its surroundings and adjust itself to get ready.
  - Do a setup when you change search areas or environment changes
- Click the “search” button
  - Search has three “steps” and takes about a minute overall
    1. Capture 30 seconds of radar signals
    2. Transfer the data files to the Toughbook
    3. Process the data and display the results



FINDER

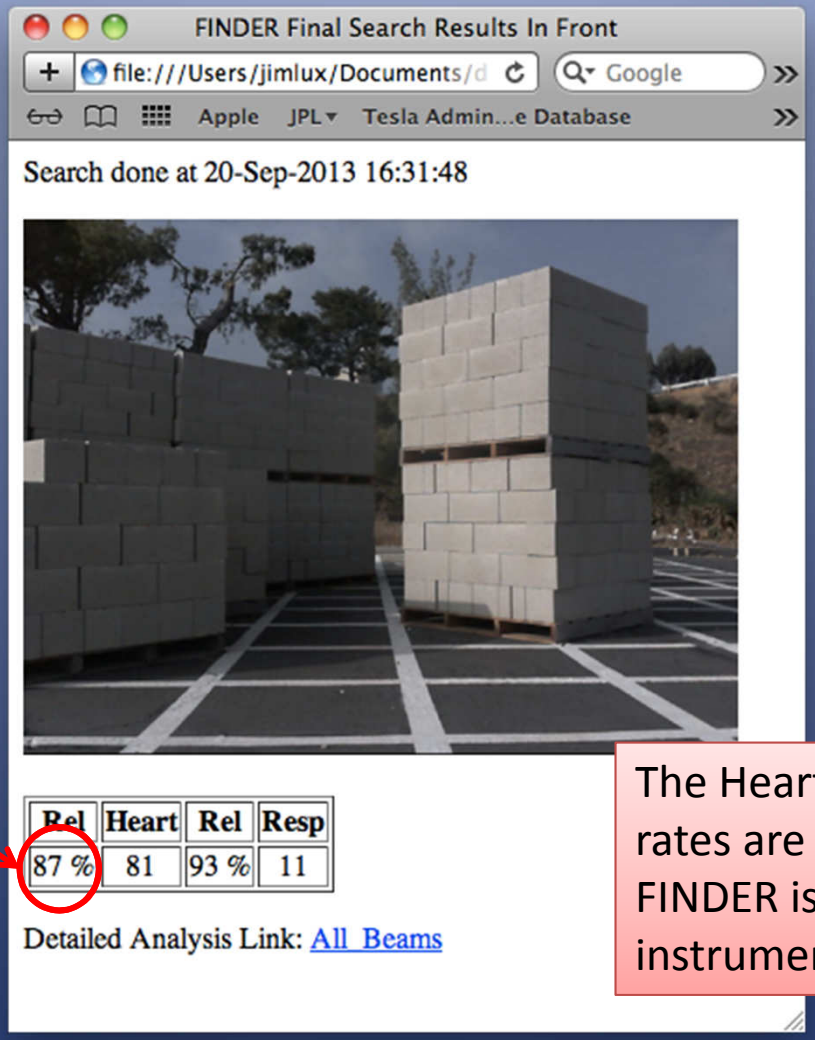
What You See on Display

Date and Time

A picture

Results

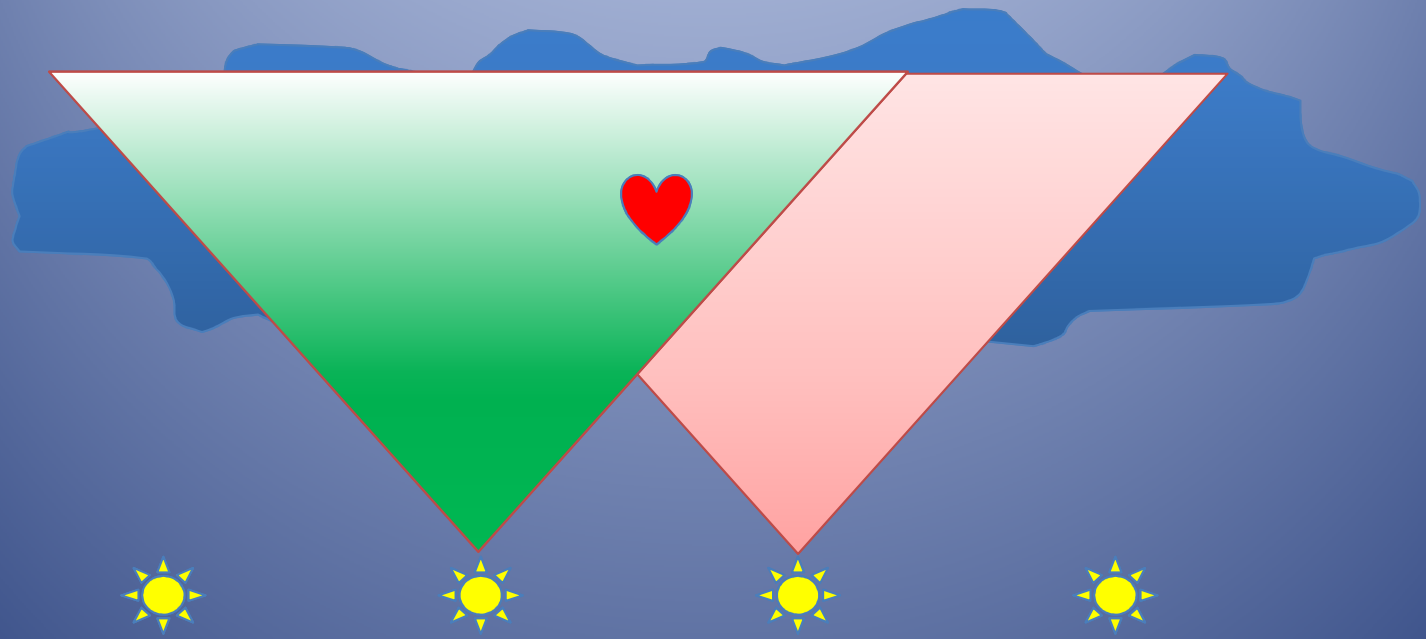
Reliability is a combination of signal strength and "humanness"



The Heart and Respiration rates are approximate; FINDER is not a medical instrument

FINDER

Search Strategy



FINDER covers an area twice as wide as far away (90 deg)
It's not a hard cutoff, much more fuzzy
Searches should be spaced about as far as the depth of search (30 ft)
That way, you get some overlap between search areas

FINDER

JPL Rubble Test Site

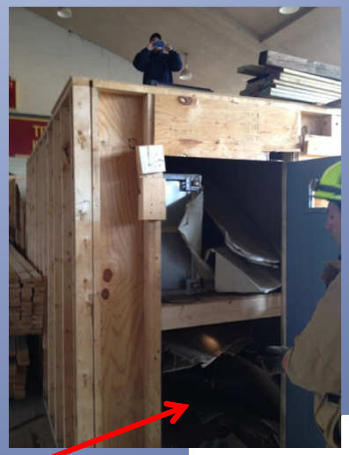
- About 20x30 meter area
- Initial test area is 28 pallets of concrete blocks
- Different kinds of rubble (concrete with and without rebar, wood, etc.)
- Leveraging on-lab demolition activity
- Lots of different scenarios possible

FINDER

Field Tests of First Prototype

Performance Goal is 10 meter penetration, 20 meter standoff
Training site in Lorton VA for Fairfax County, Virginia Task Force 1
- Rubble piles (construction debris)
- Reinforced concrete
- Collapsed buildings

Worked with USAR team members to refine design: battery life, logistics, use cases



Simulated collapsed building with sheet metal and wood

Detected victim hiding 10-15 ft inside this pipe

Victim is under here

Radar here

Victim detected here

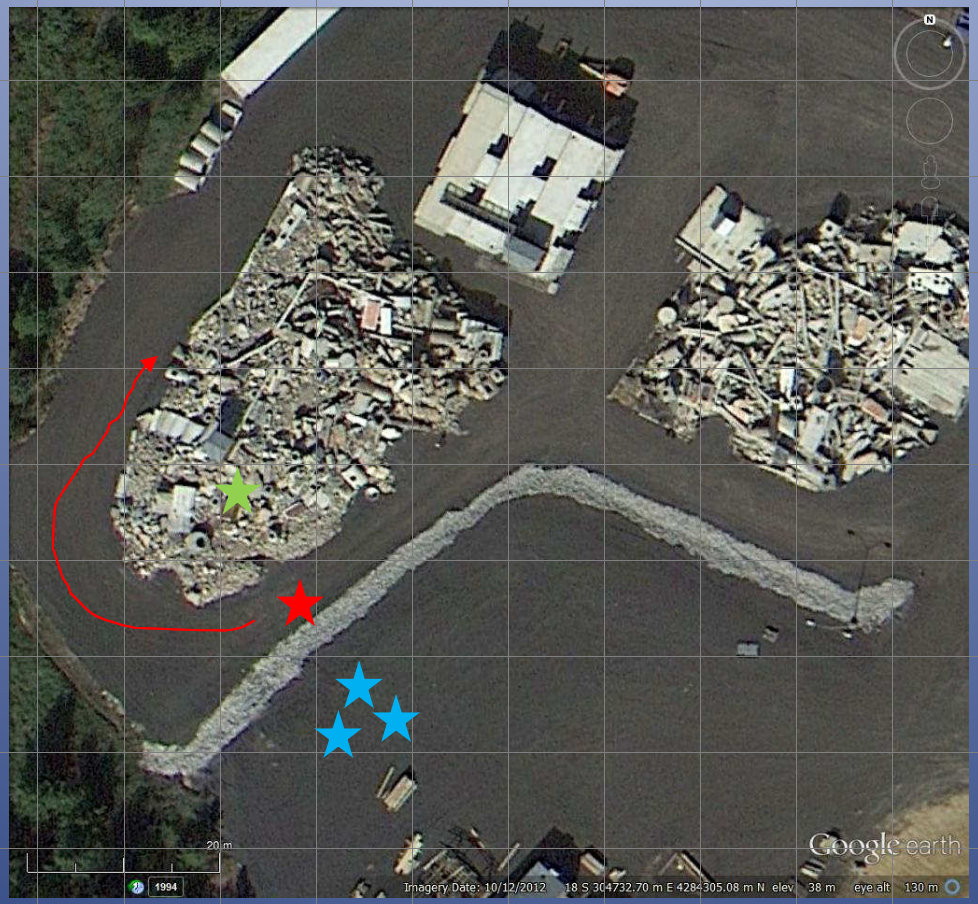
FINDER

Lorton Test Site

Victim

Finder & Operator

Rest of people



Grid is 10 meter squares

FINDER

More Testing

Bill Ingalls/NASA

FINDER

Forward into the Future

- Work with US&R and other users
  - Refine user interface
  - Improve target processing
  - Understand optimum tradeoffs between false positive/false negative
- Get it into production so lives can be saved
- Develop other uses for the sensor

FINDER